ARL 63-1

HYPERSONIC TEST STAND MODEL INSTRUMENTATION SYSTEM

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MINNEAPOLIS, MINNESOTA

JANUARY 1963

AERONAUTICAL RESEARCH LABORATORIES
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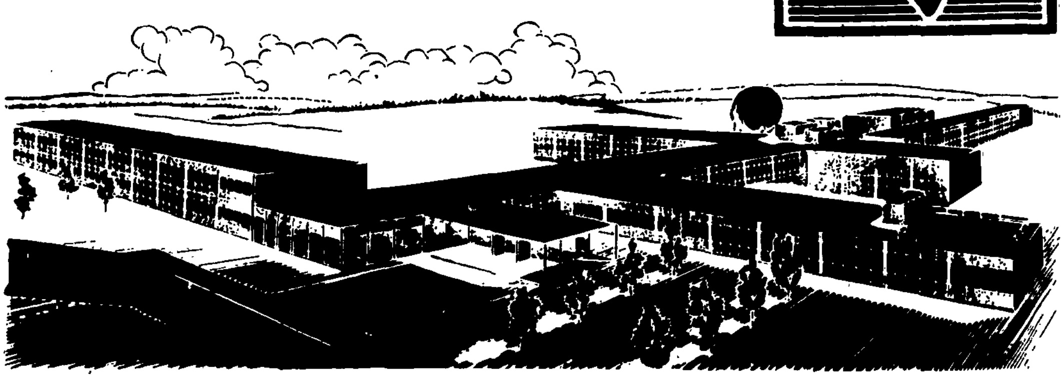

NOTICES

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CONTRACT NO. AF33(616)-7543
PROJECT NO. 7065
TASK NO. 7065-02

AERONAUTICAL RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This report was prepared by Charles Christopherson, William Hamre, Taro Matsuura and John Wastvedt of the FluiDyne Engineering Corporation, Minneapolis, Minnesota, in compliance with Contract No. 33(616)-7543. The work done by FluiDyne Engineering Corporation and described in this report was initiated under Project No. 7065 by the Aeronautical Research Laboratories with Mr. A. W. Fiore as Technical Monitor. Mr. Fiore's duties have subsequently been assumed by Mr. D. H. Murray with respect to this contract.

The development of the instrumentation systems for the Hypersonic Test Stand was carried out at FluiDyne Engineering Corporation under the direction of Mr. Robert Holdahl, Chief Engineer. Acknowledgment is made of many technical contributions by members of the staff of the Aeronautical Research Laboratories.

ABSTRACT

The model instrumentation for the Mach 14 Hypersonic Test Stand was developed to provide a means for supporting the articles in the test stand flow environment, varying the orientation of the test article with respect to the flow environment, and obtaining data on the force, pressure, and temperature loads to which the test article is exposed in the flow environment. The model instrumentation consists essentially of four sub-systems:

A Model Support System
A Model Force Measuring System
A Model Surface Pressure Measuring System
A Model Surface Temperature Measuring System

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

This report describes the Model Instrumentation Systems developed, designed, fabricated and installed into the overall facility system by the FluiDyne Engineering Corporation under Contract No. AF33(616)-7543. The facility for which this instrumentation was provided in the Mach 14 Hypersonic Test Stand of the Aeronautical Research Laboratories Office of Aerospace Research, located at Wright-Patterson Air Force Base, Ohio. The test stand employs air as a test medium with a maximum stagnation temperature of 3000°R and a maximum stagnation pressure of 2500 psi. The nominal Mach number range of the test stand is from Mach 8 through Mach 14. Run times vary from approximately 15 seconds to as long as 5 minutes. The test stand is equipped with an open jet type test section which permits test articles to be injected into and retracted from the test flow.

The goal of work described herein was to develop and provide a model instrumentation system for this facility which would permit the greatest possible utilization of this facility as a tool for the advancement of hypersonic aerothermodynamics. The system developed is intended to provide all the fundamental requirements for collecting data on test articles and transmitting this data to a data system which are not of necessity an integral part of the particular test article being investigated.

The overall system consists of two major sub-systems: the Model Support System and the Model Instrumentation System. The Model Instrumentation System in turn consists of three major sub-divisions as follows:

The Force Measuring System
The Model Surface Pressure Measuring System
The Model Surface Temperature Measuring System

These sub-systems and their interrelations are described in detail in the following sections.

SECTION II

GENERAL DESCRIPTION

The Mach 14 Hypersonic Test Stand for which the instrumentation system described herein was developed is shown in Figures 1 and 2. This test stand is one of two which share a common air supply system, the other being a Mach 20 test stand which is nearing completion. In addition to sharing the air supply system and certain other facility services such as cooling water, electrical certain other facility facility services such as cooling water, electrical power etc.; wherever practical these two stands make use of the same model instrumentation. In some case this means components are merely switched out of the instrumentation circuitry for one test stand into the instru mentation circuitry for the other. In some cases it means that components are continuously connected into the circuitry of both test stands, such as in the case of power supplies, etc. In some cases it means that equipment is actually physically removed from one test stand and transported to the other, and so forth. Because the two test stand share their air supply systems, it is not possible for both of them to be operated simultaneously; therefore the concept of sharing instrumentation equipment is logical and practical. For any given test run in either test stand, a complete integrated model instrumentation system is available.

The sub-systems which comprise the model instrumentation system described herein are shown in block diagram form in Figure 3. Those components or sub-systems which are shared with the Mach 20 facility are set out separately. For the most part, although the shared items were actually furnished under Contract No. AF33(616)-7526, their development and selection was an integral part of the work on this contract.

The console from which this equipment is operated and monitored is shown in Figure 4. This console contains the programmer which controls the motions of the model support; and the switching circuits and auxiliary equipment required to check out and monitor the force, pressure, and temperature instru mentation sub-systems, to display the information developed by thest systems, and to transmit such information to a data recording system.

SECTION III

MODEL SUPPORT SYSTEM

A. GENERAL

The Model Support System for the Mach 14 Hypersonic Test Stand can be separated into four elements as follows:

1. The Mechanical Apparatus
2. The Control and Actuation System
3. The Programmer
4. The Local Control Panel

The Model Support System provides essentially three motions to the test article as follows:

1. Injection of the test article vertically from outside of the test stream into the test stream.
2. Injection of the test article axially from a downstream location in the test stream to an upstream location.
3. Pitching of the model in the vertical plane.

The Model Support System is shown in block diagram form in Figure 5, with the operational modes shown in chart form in Figure 6.

The Mechanical Apparatus consists of the structural elements and mechanism which comprise the visually apparent model support. It provides the direct connection between the test article and the actuator drive system, and thus provides the means by which actuator motions are translated into the desired test article motions. It also provides the actual physical support of the test article and provides a path by which instrumentation leads can be routed from the test article to a point outside of the test stream, and cooling water can be routed to the test article force balance, etc.

The Control and Actuation System consists of the actual drive elements for the various motions of the mechanical appartus; and the position sensing equipment, circuitry, and the power supplies for the drive elements.

The Programmer comprises the apparatus for providing signals to the control and actuation system from the control console. It consists essentially of electrical circuitry which permits the operator to pre-select the program through which the model support, and thereby the test article, will move during a test run. It also provides a display of the actual position of the test article and auxiliary information with respect to the model support actuators power supplies, etc. The programmer hardware has been furnished under Contract No. AF33(616)-7526.

The Local Control Panel comprises a means for providing direct signals to the control and actuation system locally at the test cabin. This permits operating the model support system locally when the remote control console is connected to the Mach 20 Hypersonic Test Stand and also permits mechanics to operate the system locally during test setup.

B. PHYSICAL CHARACTERISTICS

The Model Support and its relationship to the Hypersonic Test Stand Test Cabin are shown on Figures 7, 8 and 9. The Model Support System consists of a sting socket, a strut, and a support which supports the strut in the air stream, and the necessary

actuators and mechanical linkages required to produce the desired motions and support the entire system within the test cabin.

The model support rotates the test article about a fixed point in space much in the same manner as the conventional sector type support. However, the bearings and gearing systems are not located in the plane of the strut, but are displaced to one side. This permits a considerable reduction in the actual radius of the bearing surfaces and this in turn permits design of the mechanism to provide much larger angles of attack within the same physical envelope. The pitching motion is accomplished by rotating the pitching elements on a large diameter bearing, the inner housing of which forms a clear view centered on the pitching axis.

The axial and injection motions are accomplished by sliding respective mounting plates in linear bearings. Connections from externally mounted axial and pitch actuators to the inner mechanism are via telescoping splined shafts, which permit the desired relative motions. The entire support mechanism, except for the externally mounted actuators is mounted inside the cabin on a hinged plate. This plate can be swung out of the test cabin, so that the model support mechanism and the test article can be readily removed from the tunnel for access to the test article.

The motions which this model support system provides for the test article are as follows:

1. Vertical travel: 16 inches
2. Horizontal travel: 10 inches
3. Pitch motion: from 20° nose up to 60° nose down.

The vertical injection system permits starting the test stand with the test stand with the test article outside of the test stream proper, which has the advantage of minimizing the starting problem both with respect to the facility itself and with respect to loads on the test model. It also permits protecting heat transfer models from pre-heating during start-up.

The axial motion provided permits injecting models forward into the nozzle of the test stand, after they have been injected into the test stream. This permits making the greatest possible use of the test rhombus of the tunnel flow.

The pitch motion can of course be extended to greater angles by the use of bent strings. It can also be used to provide yaw motion or combined pitch and yaw motion by rolling the test article with respect to the support system, and the use of bent strings.

The vertical injection, axial injection and pitch motions can be remotely controlled from the control console. Rolling of test articles must be accomplished between runs by removing the test article sting from the sting socket and reinserting it at a changed roll angle.

C. POSITIONING CONTROL SYSTEM

The positioning control system consists of a programmer, which is used by the operator to provide inputs to the control system; the control loops, which transmit the inputs to the actuators; and the actual actuators themselves.

The control systems are shown in block diagram form on Figure 5. The pitch control system consists of a closed loop, electrical servo system; whereas the injection systems consist of open loop, electro-hydraulic systems. The model support

programmer is shown on Figure 10. The inputs which are available via this programmer are listed below:

1. Pitch Motion
   a. Range - 60° nose down and 20° nose up
   b. Velocity - 1.5 to 2°/sec.
   c. Positions - up to 12 set points
2. Vertical Motion
   a. Inject - tunnel centerline
   b. Eject - 16 inches below tunnel centerline
3. Axial Motion
   a. Downstream position
   b. Intermediate position (adjustable)
   c. Forward position - 10 inches from downstream position

In addition to the inputs which the operator has access to via the programmer, the injection rates and accelerations can be adjusted via open loop adjustments made directly in various control elements in the hydraulic circuitry which supplies the actuators for the power of the systems.

The programmer can be used to control either the Mach 14 Hypersonic Test Stand Model Support or the Model Support for the Mach 20 Hypersonic Test Stand. It is switched from one test stand to the other via a key lock switch and the test stand selection is indicated on the programmer. When the programmer is connected to the Mach 20 test stand, it can not be used with, and it will not operate any part of, the Mach 14 test stand. However, there is in addition to the remote programmer located on the console, a local control panel located in the vicinity of the test cabin for each test stand. The control of the actuators can be exercised via the local control panel provided that a key switch on the local control panel has been turned on.

SECTION IV

MODEL INSTRUMENTATION

A. GENERAL

The Model Instrumentation systems included can be categorized as follows:

1. Force Measuring System
2. Model Surface Pressure Measuring System
3. Model Surface Temperature Measuring System

For a given test model, a generalized instrumentation system can be considered to consist of the following elements:

1. The Test Article
2. The Load Sensing Element or Elements
3. Transmission Lines from the test article to a data system.
4. Zeroing or calibration equipage between the test article and the data system.
5. The data amplifying indicating and recording system.

The relative location of the calibration equipage, etc., will vary from system to system, as will the location of the sensing element. In the present case, the instrumentation system is considered to be that part of the above between the test article and the data system. Taking the subsystems one by one, the equipment furnished can be summarized as follows:

1. Force Model Measuring System This system consists of the sensing element in the form of a three component balance complete with a water cooled jacket and sting; transmission lines to a test cabin terminal box and transmission lines from the terminal box to zeroing and calibrating equipage located in the control console, and transmission lines from the latter to a distribution panel. Equipment for loading and checking the calibration of the force balance when installed in the test stand has been made a part of this sub-system.
2. Model Surface Pressure Measuring System This system consists of sensing elements (pressure transducers), pneumatic transmission lines from a terminal point in the model support strut to the location of the sensing elements and electrical transmission lines as above for the force system.
3. Model Surface Temperature Measuring System In the case of surface temperature measurement, the sensing elements are thermocouples which are a part of the individual test article and thus are not included in the instrumentation system. The instrumentation system consists then simply of the necessary electrical transmission lines and a thermocouple reference junction located just outside of the test stand test cabin, and circuitry as required to calibrate the system when used with low impedence read-out.

In addition to the equipment described in the following paragraphs and furnished under this contract, there is available to this system additional equipment furnished under contract AF-33(616)-7526 as follows:

1. A calibration rig for the force balance.
2. A sample pressure model, calibration gear for pressure models, and additional transducers.
3. A sample temperature model.
4. An auxiliary water cooled sting for supporting test articles from the strut.
5. A six component force balance with cooled sting, cooled jacket for the balance and a sample "model."

B. FORCE SYSTEM

The force measuring system consists of a three component water cooled strain gage balance with supporting water cooled sting; an in-tunnel calibration rig for a single point before and after test calibration checking within the test stand; and the necessary electrical circuitry. It is shown in block diagram form in Figure 11.

The three component force balance itself is shown on Figures 12 and 13. The balance measures normal force, pitching moment and drag. It is protected from ambient and model heating effects by a water cooled jacket. The water connection to this jacket is made through nickel alloy bellows, minimizing the pressure effect on the force read-out. Thermocouples are installed at several locations so that the temperature gradients within the balance can be assessed. The balance is equipped with an indicator which provides a signal when the load on the balance exceeds the design value.

Strain gage bridges for the balance are conventional with each bridge consisting of four strain gages, one in each arm of the bridge. Compensation for temperature effects on zero drift and modulus of elasticity have been included.

Significant electrical and calibration data on the force balance are given on Figure 13. The loading envelope for the balance is shown on Figure 14.

The calibration rig which can be used for complete precise calibration of this force balance and which was furnished under contract AF(616)-7526 by FluiDyne Engineering Corporation is shown on Figure 15. This calibration rig permits applying the full range of loads to force balance in such a fashion that the effect on balance alignment can be corrected for throughout the load range and interactions determined.

C. SURFACE PRESSURE MEASUREMENT SYSTEM

The Surface Pressure Measurement System consists principally of a series of pressure transducers, pneumatic tubing which leads from these pressure transducers to a point tubing from a particular test article will be connected, and the necessary electrical circuitry to transmit the signals developed by the transducers to the data system. The surface pressure measurement system in block diagram form in Figure 16.

The transducers which are made a part of this system consist of two types:

Type 1. Diaphragm strain gaged type
Type 2. Thermopile type

The characteristics of these pressure transducers are summarized on Figures 17 and 18. The calibration gear, including an enclosure for a pressure model, which has been developed under contract AF33(616)-7526 and furnished there under by the FluiDyne Engineering Corporation, is shown on Figure 19. This equipment can be used to calibrate the transducers individually and also to check complete systems, including the pressure model itself, for leakage, continuity, and response.

D. SURFACE TEMPERATURE MEASUREMENT SYSTEM

The Surface Temperature Measurement System consists essentially of a thermocouple reference junction box, the necessary electrical transmission lines to transmit signals developed by the thermocouples (which are an integral part of a particular test article) from the model to the thermocouple reference junction box, and from the latter to the data system via an electrical calibration panel. The purpose of the latter is to permit calibration of the circuitry when the data system consists of a low

impedence read-out. The entire system is shown in block diagram form in Figure 20.

The system is setup for test articles employing chromel alumel thermocouples. Provision is made for two of the thermocouple leads to feed visual model temperature indicators on the control console and to operate an over temperature indicator thereon.

SECTION V

CONCLUDING REMARKS

The system described above was developed to provide for the particular needs of the Mach 14 Hypersonic Test Stand and at the same time permit maximum coordination with the Mach 20 test stand. It is not intended to provide for the needs of production type testing, nor is it intended to be tailored to any particular type of information. Its purpose is to provide the research scientist and the test engineer with with the tools needed to make effective use of the available characteristics of the test stand itself. In this respect, it is to be noted that the major burden for obtaining the desired and reliable test data remains with the research scientist in conjunction with the careful planning of the test runs to be made and the data to be required; and with the test engineer in conjunction with the proper use, calibration, and actual setup of the test instrumentation.

In conjunction with the development and furnishing of the equipment described in a general form herein, FluiDyne Engineering Corporation produced and provided to the Aeronautical Research Laboratory an Operating and Maintenance Handbook for this equipment. For those interested in greater details of this equipment and especially for potential users of this equipment, this handbook should be consulted.

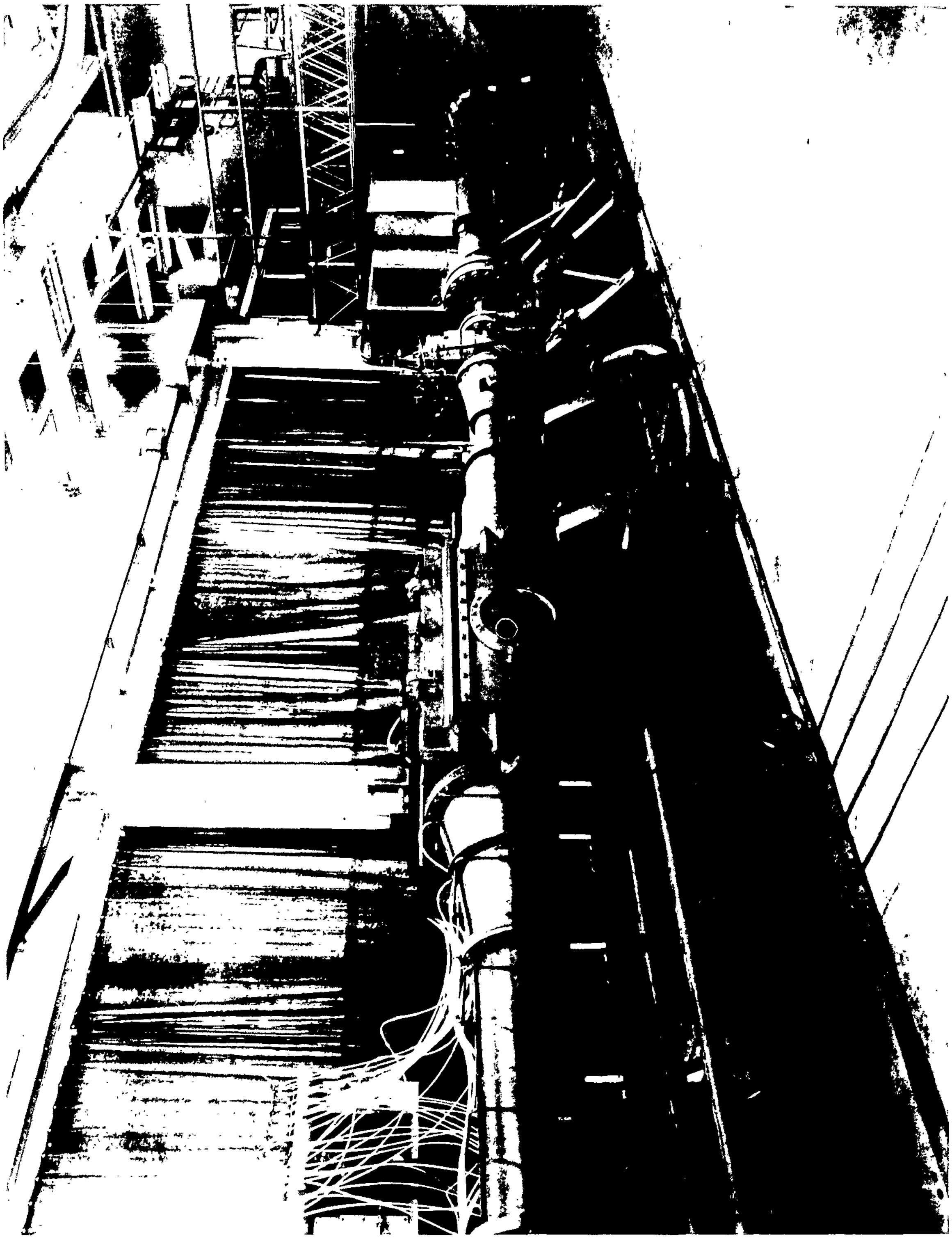

FIGURE 4 MACH 14 TEST STAND

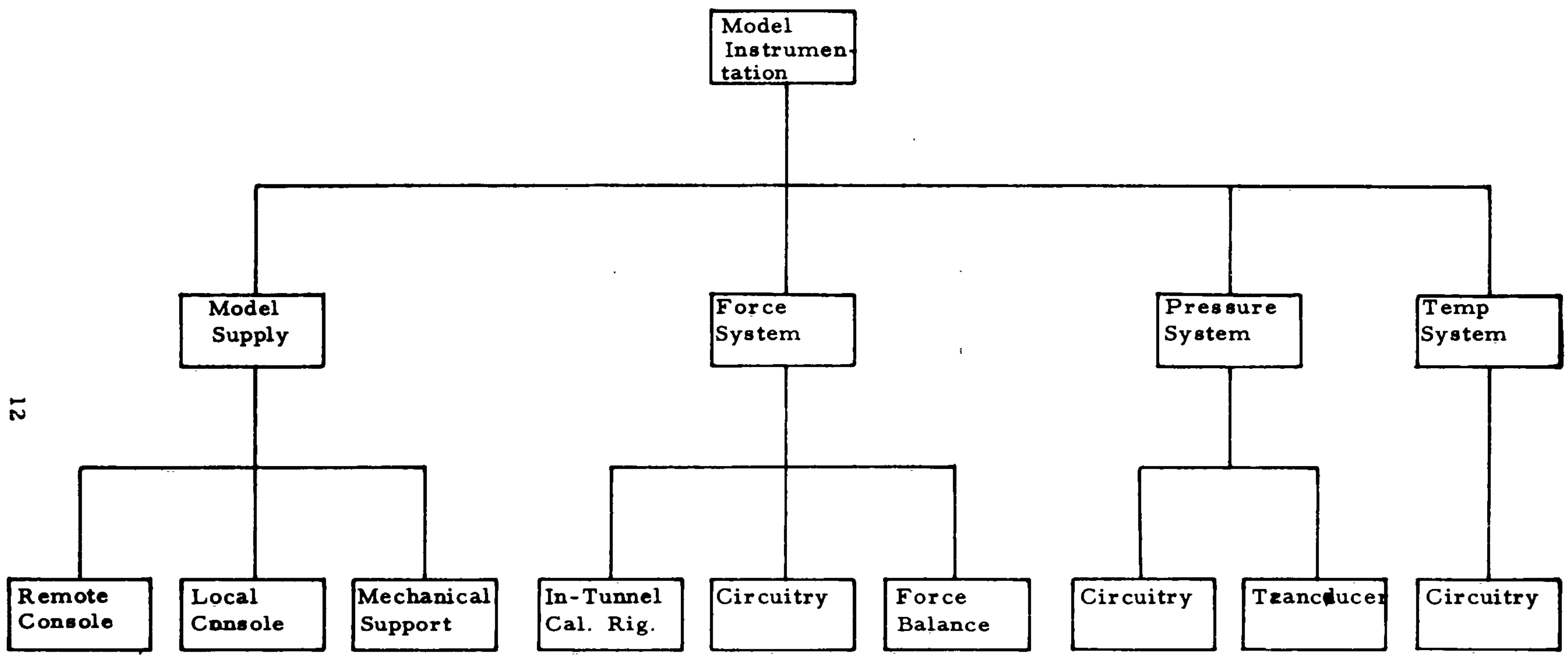

FIGURE 3. BLOCK DIAGRAM MODEL INSTRUMENTATION

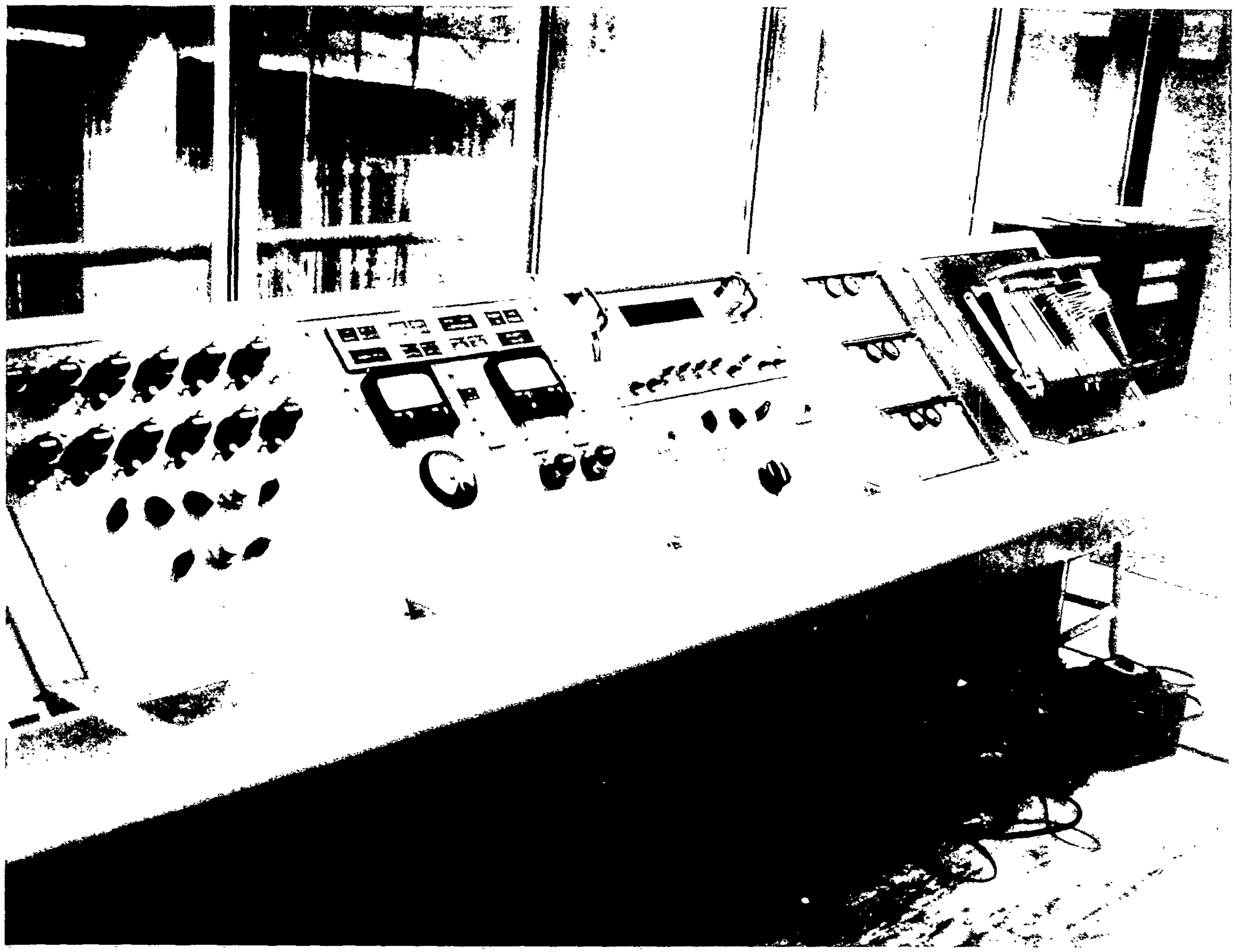

FIGURE 4 MODEL INSTRUMENTATION SYSTEM CONSOLE

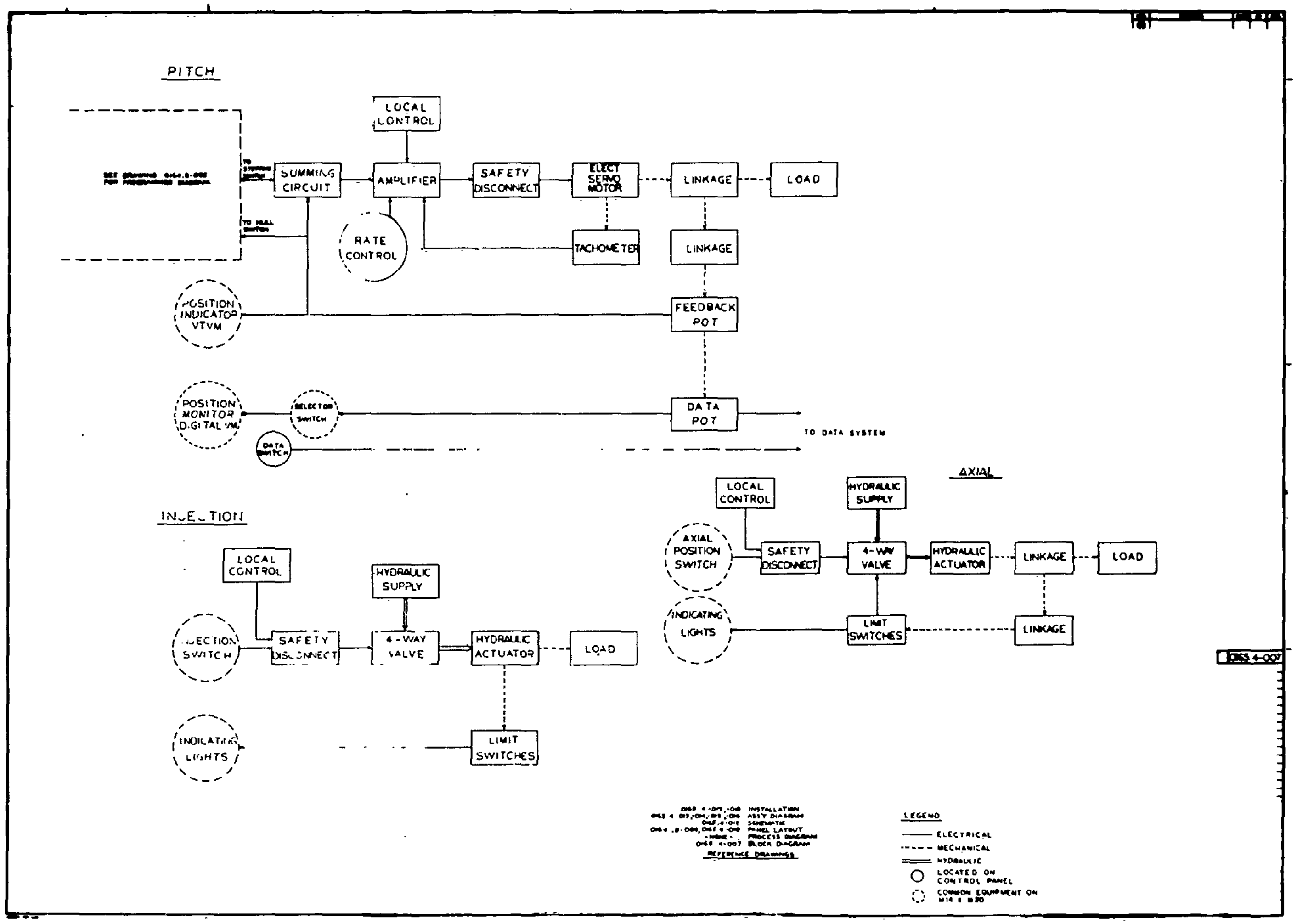

FIGURE 5. BLOCK DIAGRAM OF MODEL SUPPORT

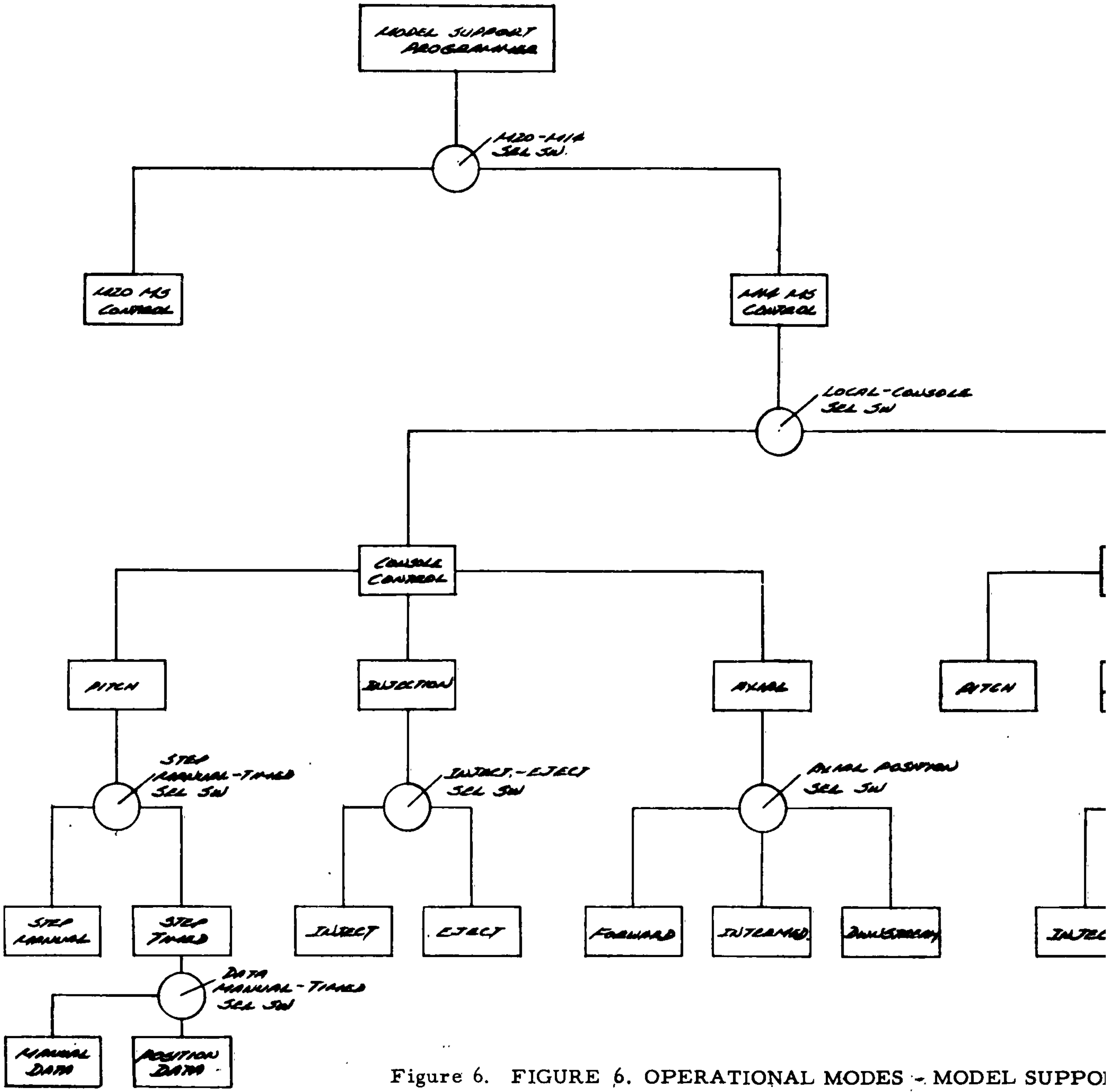

Figure 6. FIGURE 6. OPERATIONAL MODES - MODEL SUPPO

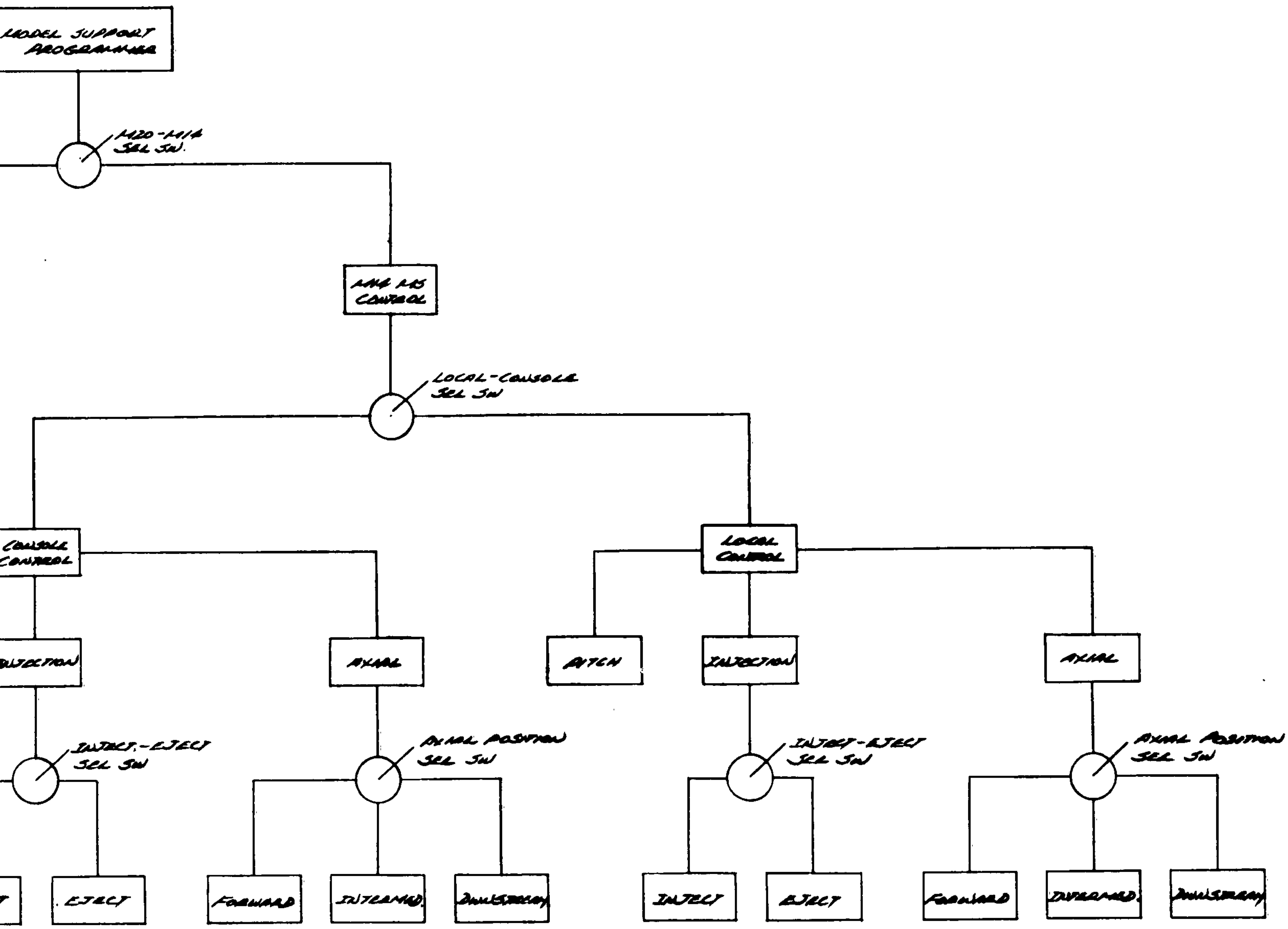

Figure 6. FIGURE 6. OPERATIONAL MODES - MODEL SUPPORT SYSTEM

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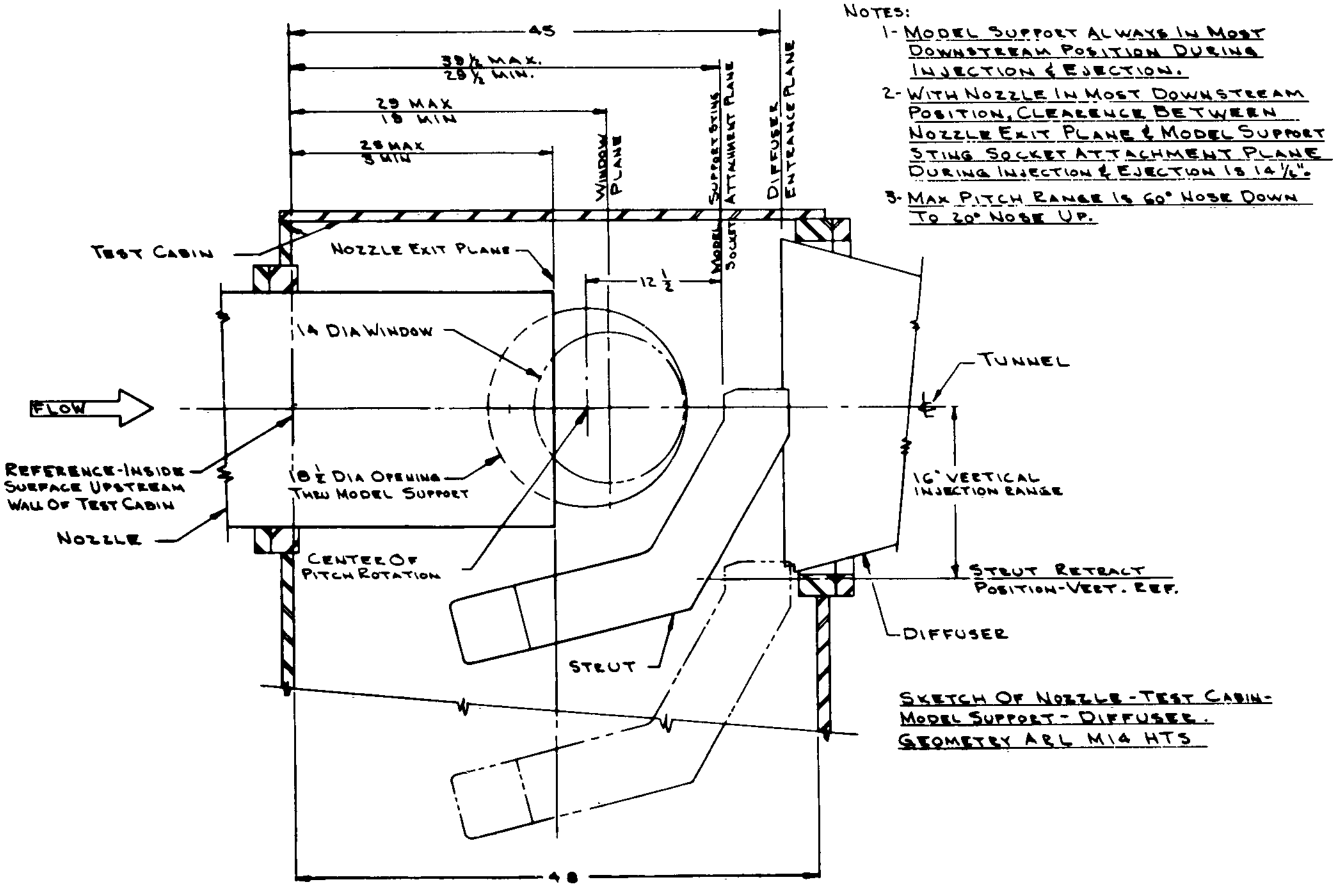
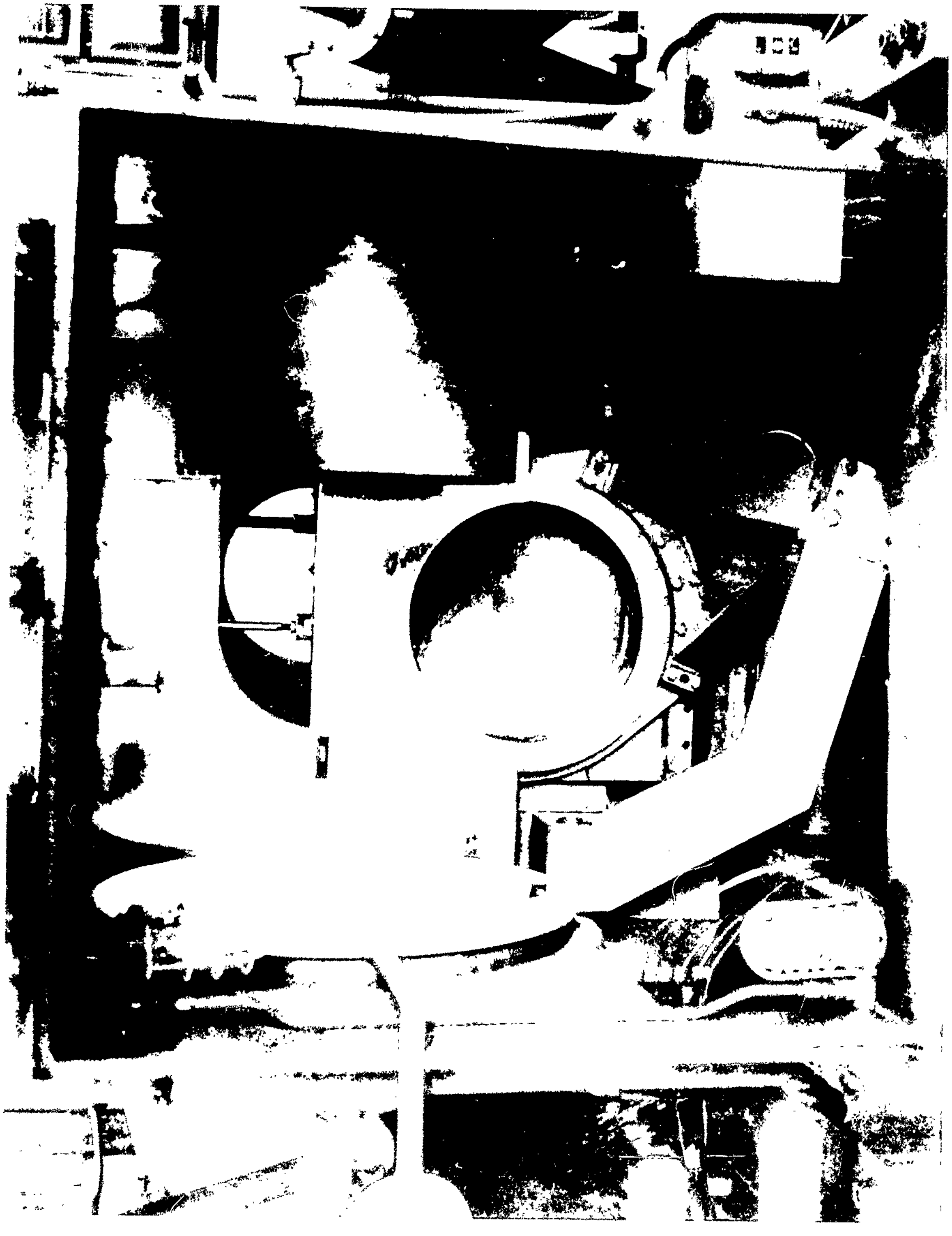


FIGURE 7. MODEL SUPPORT



FIGURE

FIGURE [illegible] SUPPORT

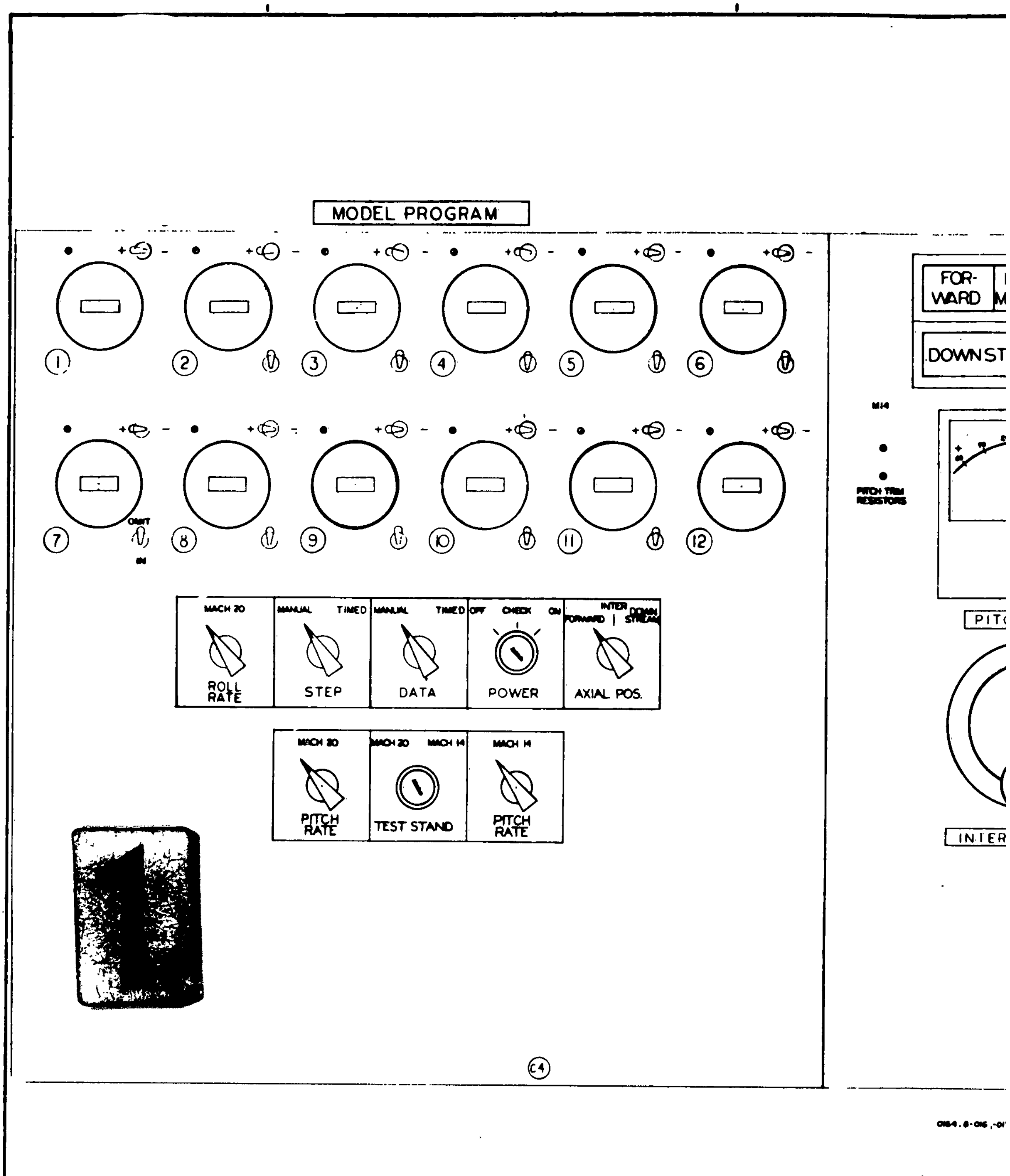
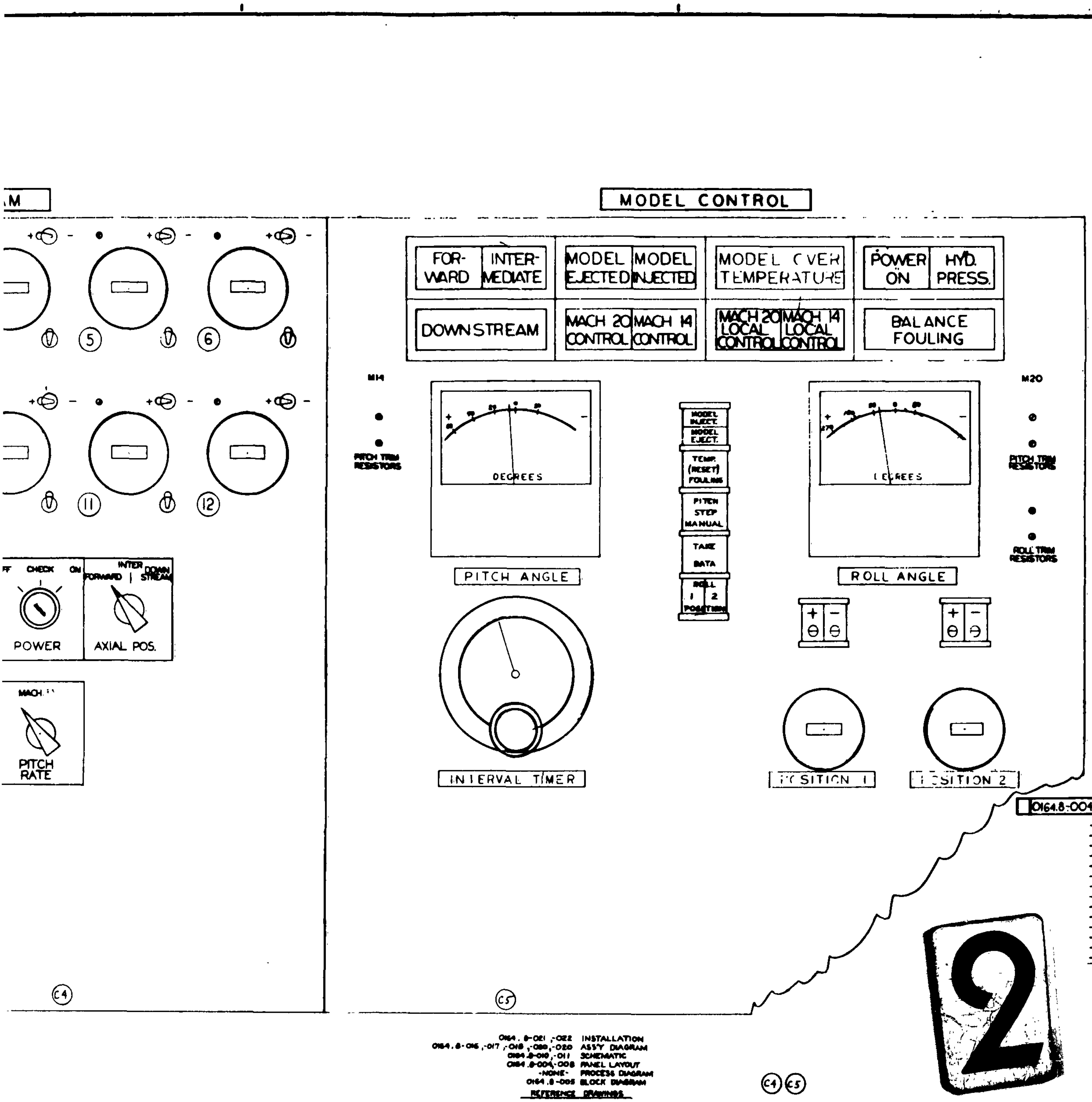


FIGURE 10 MODEL SUPPORT PROGRAMMER



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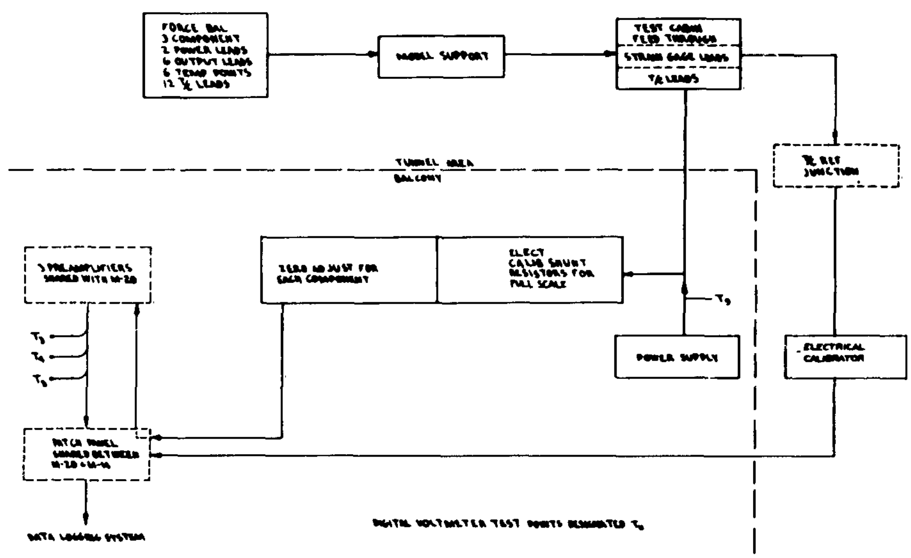


FIGURE 11 BLOCK DIAGRAM -FORCE SYSTEM

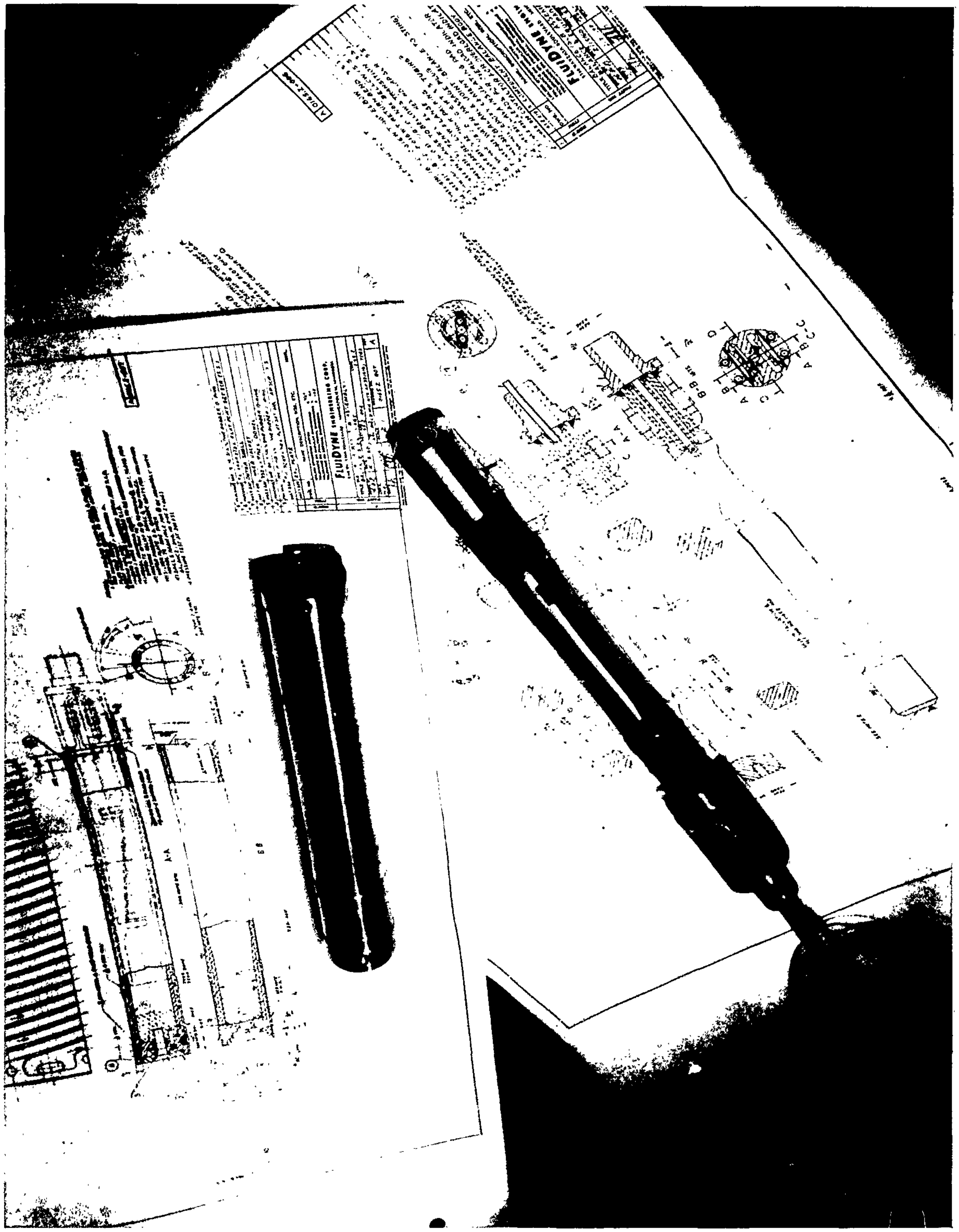


FIGURE 12 FORCE BALANCE

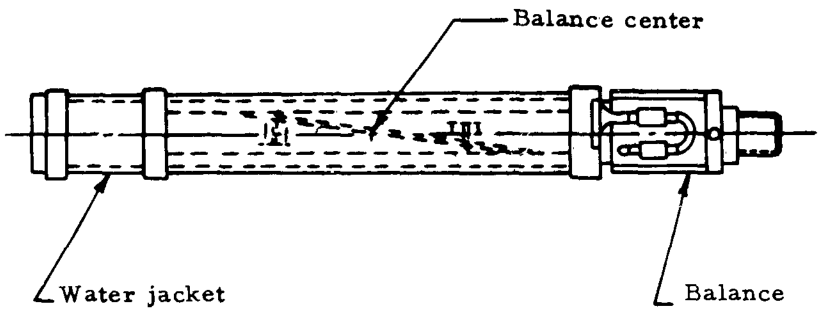


FIGURE 13 FORCE BALANCE

Characteristics of the Force Balance

Nominal Load Range

Normal	82 lbs. - 90 lbs.
Pitching Moment	185 in-lbs. - 205 in-lbs.
Axial	50 lbs.

Electrical Characteristics

Bridge Voltage	5 volts AC or DC
Bridge Resistance	- 120 ohms
Sensitivity:	
Front Normal Force Bridge	
Normal Force	.00509 mv/volt/lb.
Pitching Moment	.00227 mv/volt/in-lb.
Rear Normal Force Bridge	
Normal Force	.00541 mv/volt/lb.
Pitching Moment	.00243 mv/volt/lb.
Axial Force Bridge	
Axial Force	.03025 mv/volt/lb.

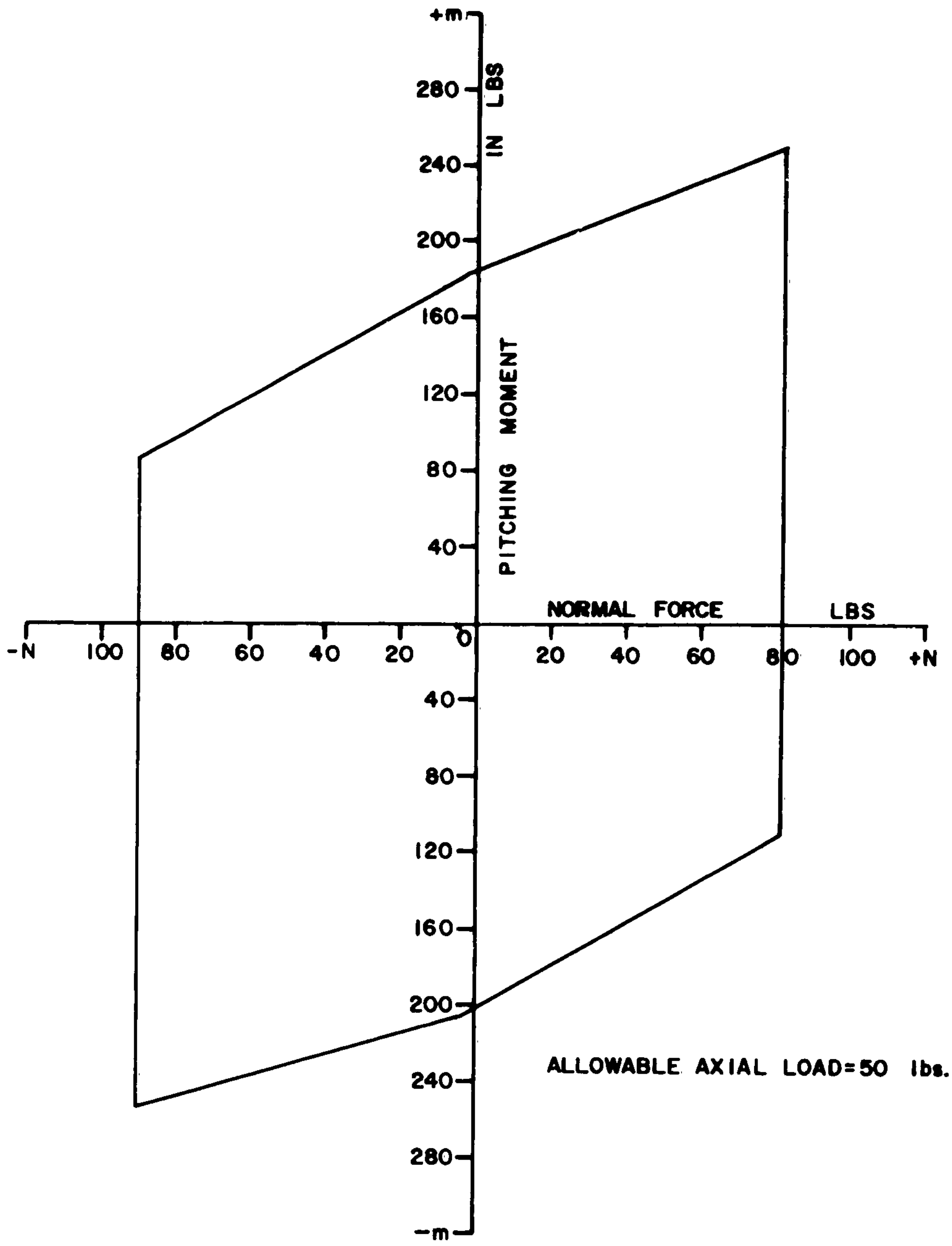
Temperature Effects

Sensitivity - less than 1/2% of full scale for $T \quad 100^{\circ}$

Zero Drift - less than 1/2% of full scale for $T \quad 100^{\circ}$

Interactions

Axial Force on Normal Force - less than 0.1%
Axial Force on Pitching Moment - less than 0.1%
Pitching Moment on Axial Force - 8.7%
Normal Force on Axial Force - 2.5%



LOADING ENVELOPE

FIGURE 14 FORCE BALANCE LOAD ENVELOPE

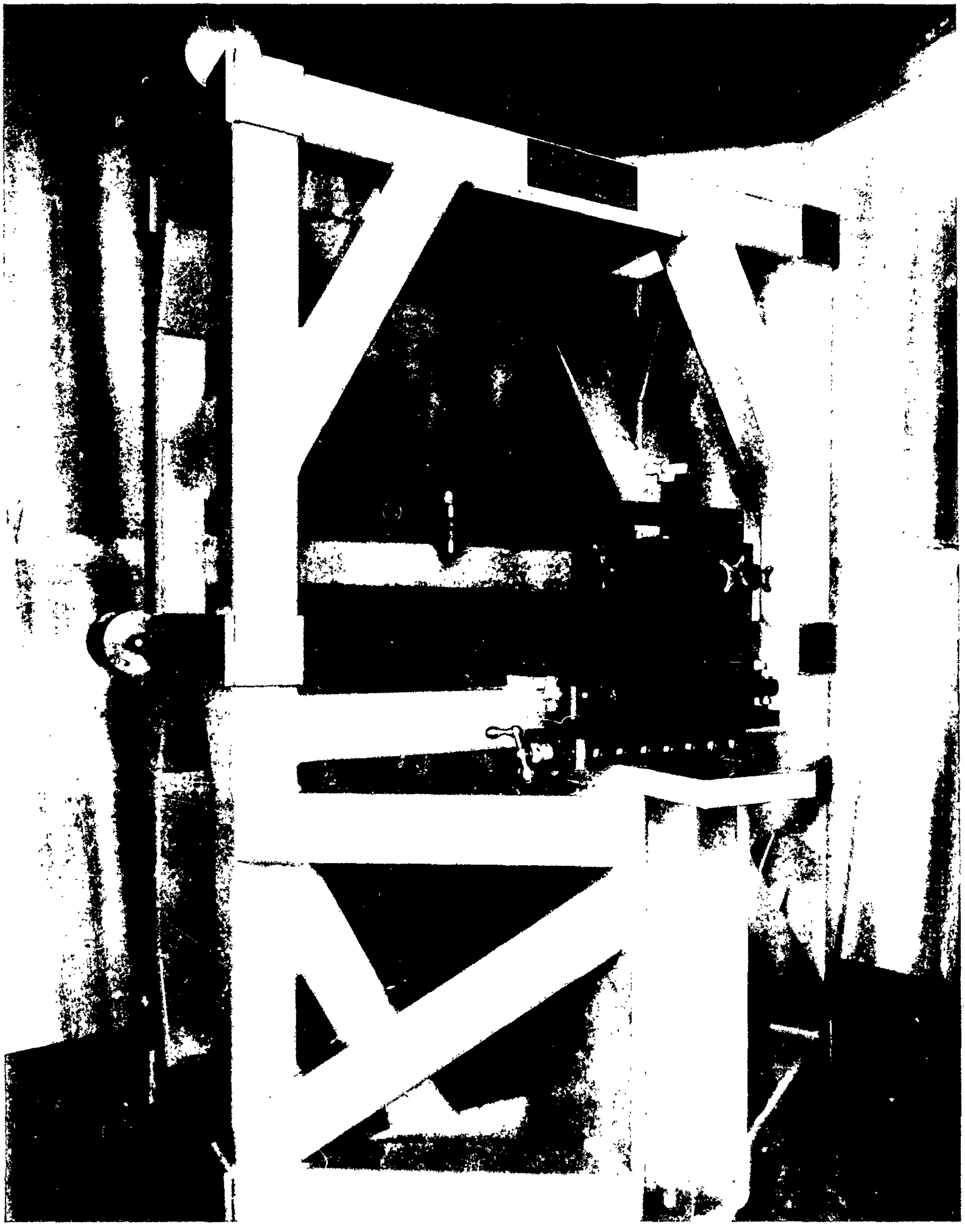


FIGURE 15 FORCE BALANCE CALIBRATION RIG

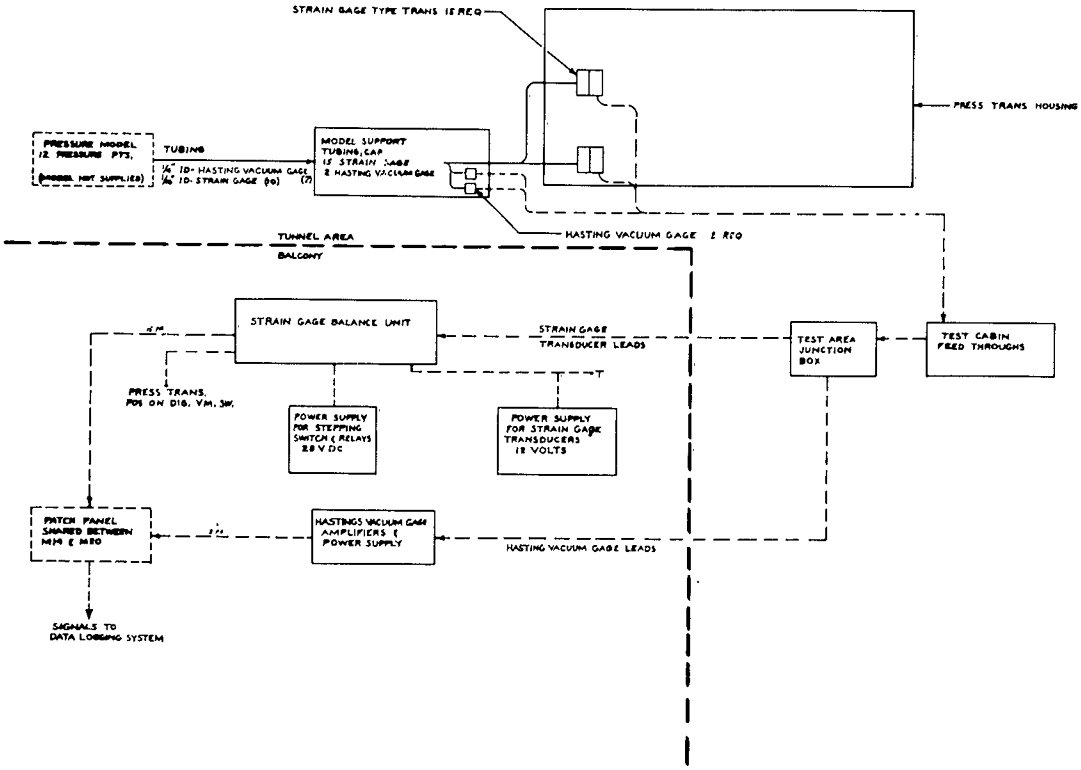


FIGURE 16 BLOCK DIAGRAM-PRESSURE SYSTEM

FIGURE NO. 17

Diaphragm Transducer Characteristics

Statham (Model PA295TC) ABS. Pressure Transducer
- Range: 0 - 5 psia
- Maximum Overload: 300% of rated range
- Nominal Bridge Resistance: 350
- Excitation: 7 volts DC or AC (RMS) through carrier Frequencies
- Full scale output: Approx. 56 mv at 7 volts
- Resolution: Infinite
- Non-Linearity and Hysteresis: Less than $\pm$ 0.75% of FS
- Ambient Temp. Limit: -100°F. to 275°F.
- Compensated Temp. Range: -65°F. to 250°F.
- Thermal Sensitivity Shift: Less than 0.02%/$^{\circ}$F.
- Thermal Zero Shift: Less than 0.02% FS/$^{\circ}$F
- Pressure Connection: 7/16-20 UNF-3A Per MS33656E4 External Thread
- Electrical Connection: Case Mounted Bendix PC1H-8-4P

FIGURE NO. 18

Thermopile Transducer System Characteristics

Hastings-Raydist Model GV-31A with type DV-13 Gauge Tube
- Range: Variable 0-250 Microns Hg FS to 0.1-20 mm Hg FS
- Full Scale Output: 0-1 mv DC for 0-250 microns hg.
0-10 mv DC for 0.1 - 20mm Hg.
- Accuracy: 1% of pressure reading
- Temperature Limit: Ambient to 300°F.
- Internal Volume: .003 cubic inches
- Pressure Connection: 1/4 - 28 UNF male thread with O-ring seal
- Power: Regulated Input 115 volts AC 60 cycles with regulation 95 - 135 volts
Nonregulated Input 115 volts AC 50 - 1000 cycles.

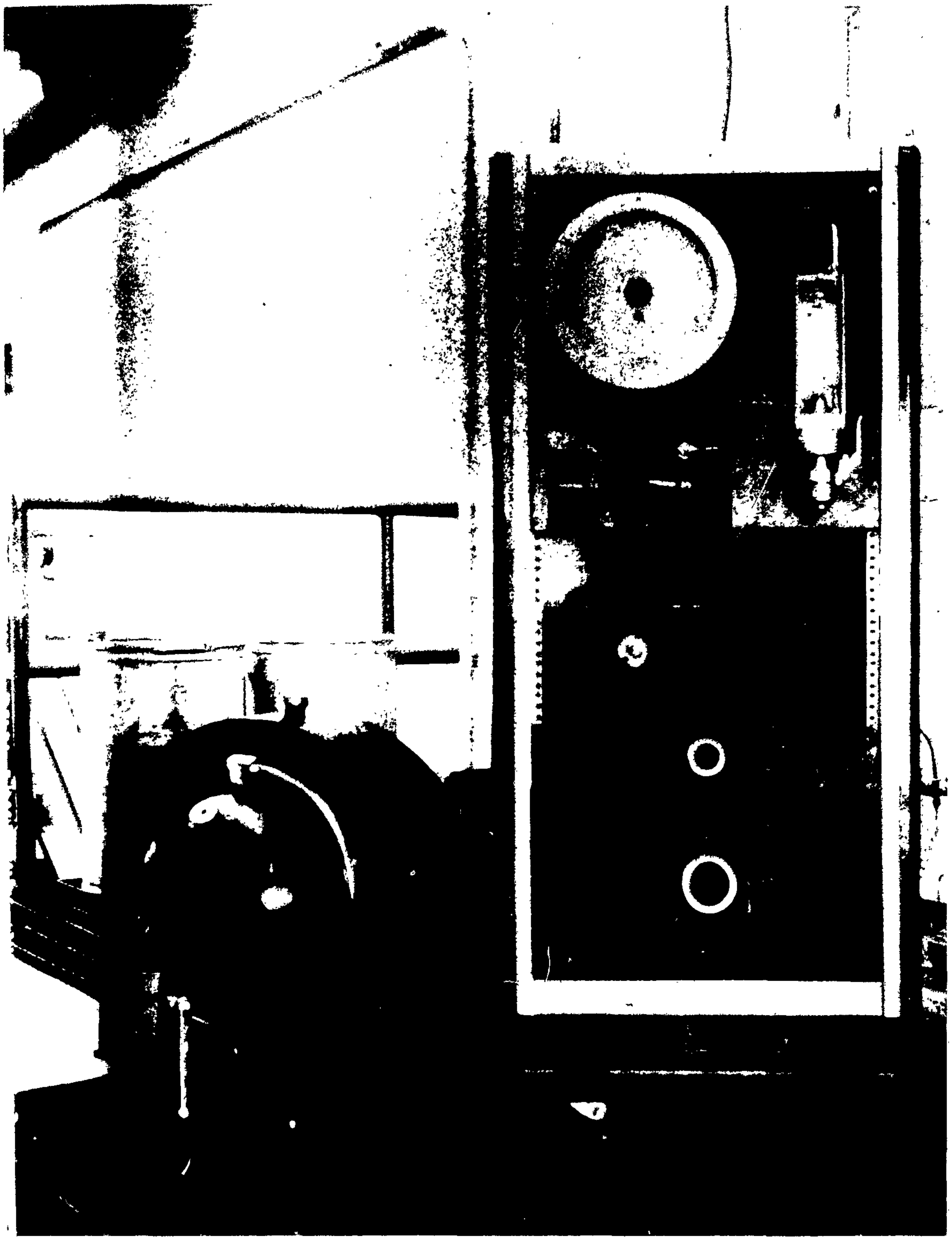


FIGURE 14 PRESSURE SYSTEM CALIBRATION RIG

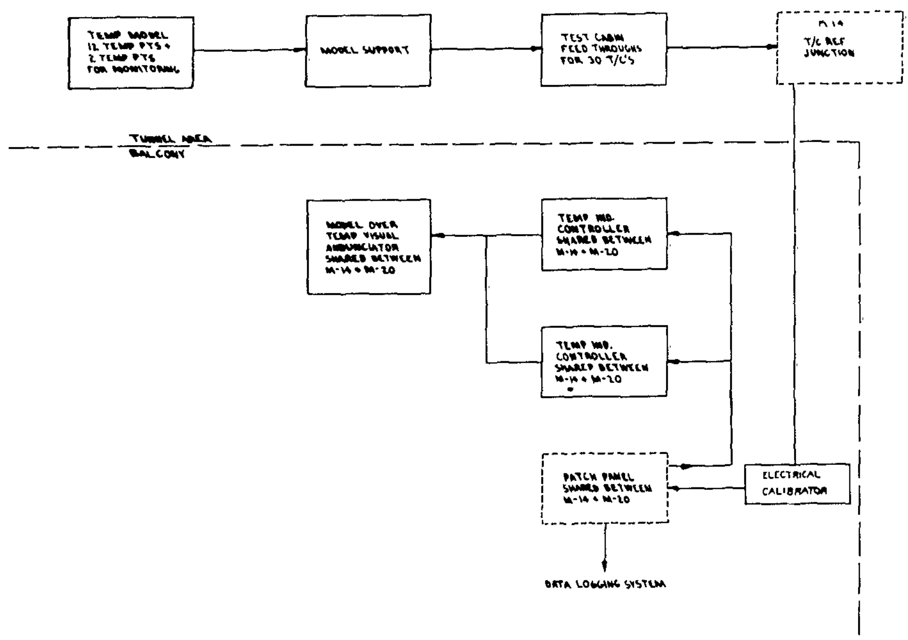


FIGURE 20 BLOCK DIAGRAM-TEMPERATURE SYSTEM

Aeronautical Research Laboratories, Wright-Patterson AFB, O. HYPERSONIC TEST STAND MODEL INSTRUMENTATION SYSTEM by Charles Christopherson, William Hamre, Taro Matsuura, John Wasthedt, Fluidyne Engineering Corp., Minneapolis, Minn. January 1963. 28 p. inclu. illus. tables. (Project7065; Task 7065-02) (Contract AF 33(616)-7543) (ARL 63-1)

Unclassified Report

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